Technical Note N-1308

COMPRESSIVE STRENGTH OF 67-YEAR OLD CONCRETE SUBMERGED IN SEAWATER

By

H. H. Haynes and P. C. Zubiate, Jr.

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, CA 93043

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ABSTRACT

Core specimens were obtained from six concrete blocks submerged partly or totally in seawater for 67-years off the Los Angeles Harbor breakwater. The compressive strengths of the concrete were compared with strengths of 40 years earlier. It was found that two blocks increased in strength, three remained the same and one decreased. The blocks still showed fairly sharp edges and original form marks. Rock boring mollusks were found on the surface of the blocks but they did not damage the concrete.

INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) assisted the University of California at Berkeley (UCB)[1] in obtaining core specimens from 67-year old concrete blocks located off the San Pedro arm of the Los Angeles Harbor breakwater. NCEL desired to learn of the long-term compressive strengths of the concrete because of the Navy's interest in undersea pressure-resistant concrete structures.[2] UCB desired samples from the blocks to investigate the mechanism of deterioration of concrete.

BACKGROUND

In August 1905, the U. S. Army Corps of Engineers began a long-term durability study on unreinforced concrete exposed to the marine environment. Eighteen concrete blocks of size 5.75 ft. square by 3.5 ft. high were cast using three mixes and six brands of cement (Table 1). Compressive strengths were not obtained from these concretes at the time of casting.

In 1932, the Corps of Engineers returned to evaluate the 27-year old concrete. It appeared that the tops of most of the blocks were 1 to 5 ft. above mean lower low tide. The blocks were covered with dense growths of marine grasses and shells. The concrete showed no signs of deterioration as evidenced by the sharp corners and edges of the blocks (Figure 1).[3] Three-inch diameter core specimens were taken from the blocks for compressive strength tests. The blocks were replaced on the breakwater with their tops 2 to 6 feet above low water.

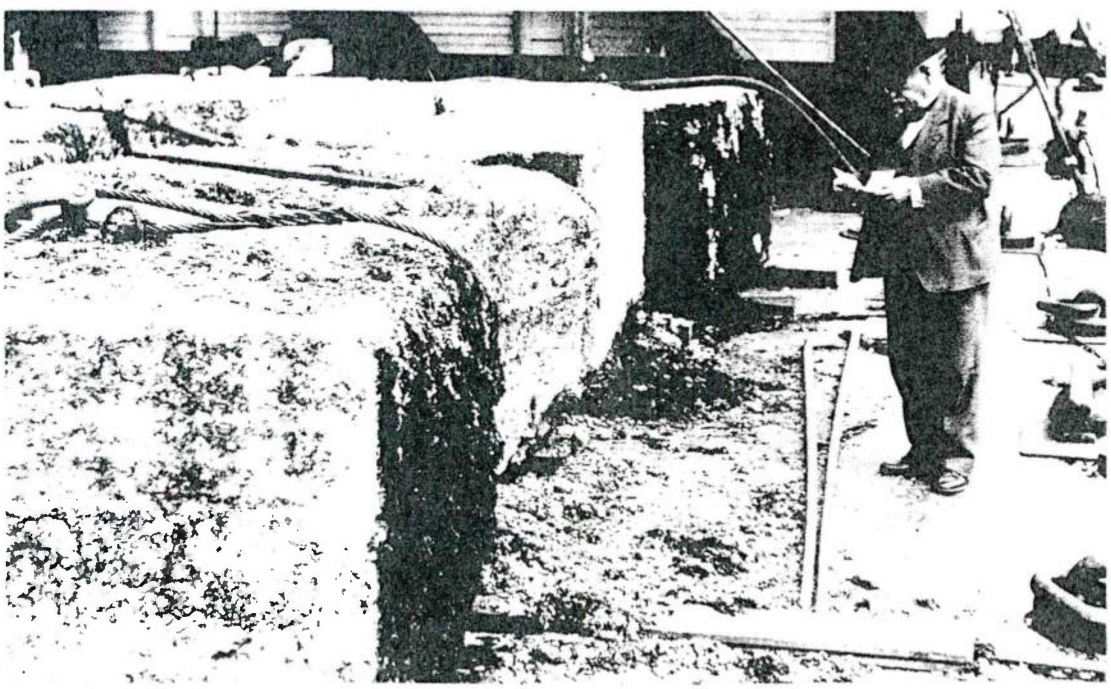

Figure 1. Condition of concrete blocks in 1932.

Table 1. Concrete Blocks

Block Designation[a/]	Old Location April 25, 1932 (Station)	New Location July 7, 1972 (Station)	Water Depth (ft)
A1	32 + 24	32 + 24	30
A2	32 + 50±	-	-
A3	33 + 44	33 + 44	25
A4	32 + 18	32 + 18	12
A5	33 + 50	32 + 18	30
A6	32 + 34	32 + 10	20
B1	31 + 84	31 + 84	30
B2	31 + 77	-	-
B3	31 + 70	-	-
B4	31 + 63	-	-
B5	31 + 57	(same as old location) -	-
B6	31 + 98	-	-
C1	30 + 27	-	-
C2	30 + 32	-	-
C3	30 + 63	-	-
C4	30 + 22	-	-
C5	30 + 14	-	-
C6	30 + 46	-	-

a/ Letter designates mixes: A, 1-2-4 (cement-sand-rock by volume)
B, 1-3-6
C, 1-2.5-5, with 4 parts of granite boulders weighing 20 to 100 lbs each

Numeral designates cement brand: 1, Gillingham
2, Germainia
3, Alsen
4, Iola
5, Standard Napa
6, Colton

PRESENT OPERATION

By July 5, 1972, all the blocks had slid off the breakwater to totally submerged locations. Navy Seabee divers located eight blocks, of which six were rigged for removal. Of the remaining two blocks, one (B-2 or B-3) was in 50 feet of water and buried in sand except for a corner and the other (B-5) was wedged among granite boulders. Attempts were made to find only the A and B series blocks.

The blocks were lifted, one at a time, onto a Naval YFU vessel for the coring operation (Figure 2). A 4-inch diameter core was drilled through the 3.5 foot thickness of the block. Then the blocks were returned to a submerged location. Table 1 gives the new locations.

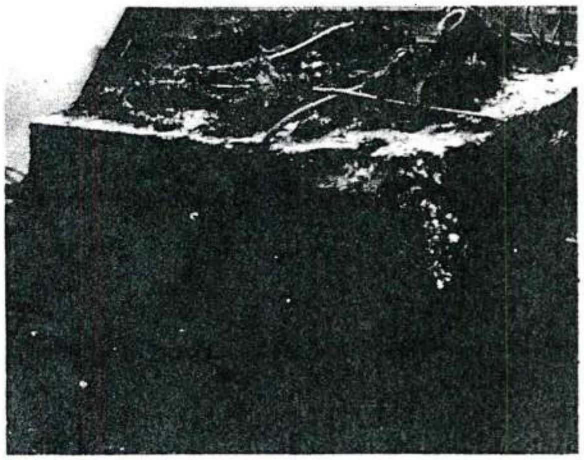

Figure 2. Condition of block A-6 in 1972.

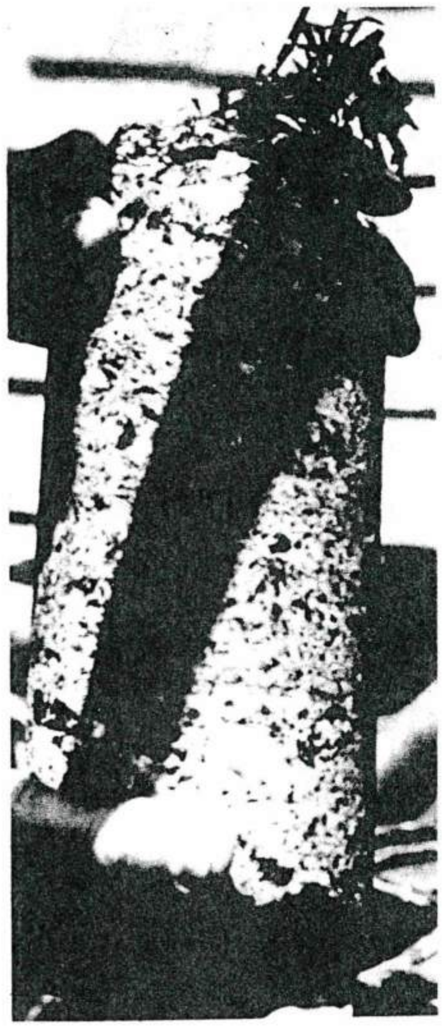

Figure 3. Core specimen showing concrete in 1972.

Table 2. Compressive Strength Results

Block Designation	Concrete 27 Years Old			Concrete 67 Years Old			Increase[a] In Strength (%)
	No. of Specimens	Compressive[b] Strength (psi)	Standard Deviation (psi)	No. of Specimens	Compressive[c] Strength (psi)	Standard Deviation (psi)	
A1	3	5,910	590	7	4,260	500	-38.7
A3	3	4,690	450	6	5,210	1160	+10.0
A4	3	6,010	560	8	6,020	560	0.0
A5	3	4,940	1130	7	5,060	250	+ 0.2
A6	3	3,570	620	7	4,970	400	+39.2
B1	3	2,180	750	7	3,060	750	+28.8

a/ $\frac{\text{67 yr. strength} - \text{27 yr. strength}}{\text{67 yr. strength}}(100)$

b/ core specimen size was 3x3 in.

c/ core specimen size was 4x4 in.

RESULTS

Table 2 represents the compressive strengths of the concrete at age 27 and 67 years. The results showed that over the past 40 years two blocks (A-6 and B-1) increased in strength, three blocks (A-3, A-4 and A-5) remained the same strength and one block (A-1) decreased in strength.

Visual inspection of the blocks showed no apparent deterioration of the concrete. The corners and edges of the blocks were rounded to varying degrees but most of the edges were still fairly sharp. Original form marks were still clearly visible on many of the blocks (Figure 4).

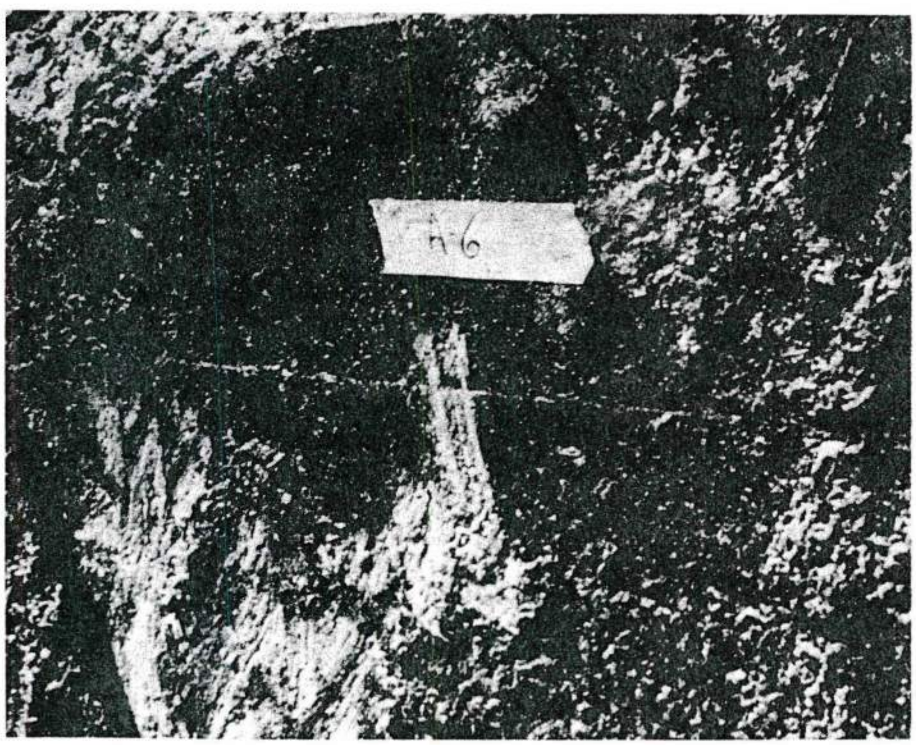

Figure 4. Original form marks are apparent on block A-6.

Vegetation growth on the A blocks was light. Block B-1 was covered with large clusters of fixed snail tubes, aletes squamigerus. Samples of concrete from the first six inches of the core segment nearest the surface for blocks A-3 and B-1 were analyzed for Ph values to determine whether the growth difference could have been caused by a difference in alkalinity. The Ph values were essentially the same; A-3 was 10.5 and B-1 was 10.9. Some factor other than Ph was probably the cause for the growth difference between the A and B blocks.

The salinity of the above concrete samples was also determined and found to be low; A-3 was 1.7 ppt and B-1 was 1.5 ppt. A seawater sample obtained at the breakwater location showed a salinity of 33.4 ppt (the Ph was 6.80).

The concrete was inspected by a marine biologist for evidence of rock boring mollusks. Mollusks were found on the concrete surface to a limited extent and they had bored into the concrete to about 1/8-inch. In one case on block B-1, the penetration was 1/4-inch. It appeared that the granite aggregate prevented the mollusks from penetrating further. The conclusion from these observations was that the concrete showed excellent resistance to the mollusks over a 67 year period in a location known to contain borers.

On block A-5, an attempt was made to remove a core segment that contained a 1-inch diameter steel rod which was part of the original lifting U-bolt. This attempt was unsuccessful, so instead, the concrete was chipped away from the rod to a depth of 8 inches. At the surface of the block, the rod was corroded away leaving only the tip of a cone. At 2 inches down the rod was at full diameter. From 2 to 4 inches, moderate to light corrosion was found around the circumference of the rod; from 4 to 6 inches, light corrosion products were found on only one side of the rod; and from 6 to 8 inches, the rod was smooth and clean.

Microstructure examination of the concrete was conducted at the University of California at Berkeley and resulted in the following findings:[5]

> "X-ray diffraction analyses from the mortars taken from the crushed concrete cores of A showed considerable cementing constituents, tobermorite and $Ca(OH)_2$, to be still present in the interior concrete. Argonite, calcite, ettringite and hydrocalumite were detected to be the other minerals present. It is interesting to point out that hydrocalumite $Ca_{16}Al_8(OH)_{54}CO_3 \cdot 21H_2O$, normally occurs in natural raw materials.
>
> In addition to the constituent minerals mentioned above, an upper core from the B block had a lot of white material in the interior. On X-ray diffraction examination, the material was found to be brucite, $Mg(OH)_2$. It appears that brucite forms as a result of decomposition of tobermorite gel and $Ca(OH)_2$ of portland cement by the action of magnesium sulfate present in seawater:

$$Ca(OH)_2 + MgSO_4 \cdot 7H_2O = Mg(OH)_2 + CaSO_4 \cdot 2H_2O$$

$$3CaO \cdot 2SiO_2 \cdot 3H_2O + 3MgSO_4 \cdot 7H_2O = 3Mg(OH)_2 + CaSO_4 \cdot 2H_2O + 2SiO_2 \cdot H_2O.$$

Accordingly, both $Ca(OH)_2$ and tobermorite gel (the main binder in concrete) were absent by X-ray diffraction analysis of this specimen. Incidently, this confirms the preliminary results based on chemical analysis in the 1932 investigation reported earlier (that was - - - the chemical analysis of the mortars showed some of the lime from the hydrated cements to have been leached away and replaced by magnesia)."

In summary, the concrete from the A blocks was not attacked by the seawater. However, the concrete of block B-1 had the tobermorite gel and $Ca(OH)_2$ of portland cement converted to brucite, $Mg(OH)_2$, by the action of magnesium sulfate present in seawater. The compressive strength gain of the concrete of block B-1 may have been due to the formation of brucite.

SUMMARY

Over the past 40 years, the compressive strength of six 67-year old concrete blocks submerged partly or totally in seawater was found to increase for two blocks, remain the same for three blocks, and decrease for one block. Deterioration of the concrete was not evident from visual inspection or microstructure examination. The resistance of the concrete to rock boring mollusks was excellent.

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